

DOCUMENT RESUME

ED 261 351

CS 008 150

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TITLE The History of Computers and Their Use in Education.
PUB DATE Dec 82
NOTE 36p.; Paper presented at the Annual Meeting of the National Reading Conference (32nd, Clearwater, FL, December 4-6, 1982).
PUB TYPE Information Analyses (070) -- Speeches/Conference Papers (150) -- Viewpoints (120)
EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS *Computer Assisted Instruction; Computer Literacy; *Computers; Educational Development; *Educational History; Educational Philosophy; Educational Research; Elementary Secondary Education; Futures (of Society); Higher Education; *Intellectual History; Inventions; Teaching Methods; *Technological Advancement

ABSTRACT

Intended for educators at all levels, this paper traces the development of the computer from its beginnings to the present and discusses how computers can best be used in education. The first section of the paper describes major developments in the history of the computer, including the machine invented by W. Schickard and the computer constructed by B. Pascal in 1642 to complete mathematical functions; the "Leibniz Wheel," devised by G. W. Leibniz in 1673; the various inventions of G. Babbage in the 1800s; the early digital computers developed in the 1930s and 1940s; the construction of the Electronic Integrator and Calculator (ENIAC), which led to a number of advances in computer technology; and the technological breakthroughs that led to the development of minicomputers and microcomputers. The second section of the paper, based on a review of recent computer-related research, traces the growth of computer use in education. Research examined in this section is organized into six categories: (1) computer assisted instruction, (2) attitudes towards computers, (3) computer testing, (4) computer managed instruction, (5) cost effectiveness, and (6) computer literacy. The paper concludes with a series of questions educators need to ask about computer use, noting that the answers can lead them to realize that the computer can--and is likely to--cause a dramatic change in teaching and learning. (FL)

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THE HISTORY OF COMPUTERS
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Paper presented at the National Reading Conference's Annual Meeting
Clearwater, Florida
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The History of Computers
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Under a broad definition, we can trace computers to ancient times when man started to use pebbles, calculi in Latin, as an aid in counting and extension of memory. But under a narrower definition, we can only go back in time to an Iranian mathematician, Al-Kashi, who constructed two special purpose computers, a lunar eclipse and a planetary computer (Goldstine, 1972).¹

Era of Modern Computers

However, the era of general purpose computers began with Wilhelm Schickard, a professor of astronomy, mathematics, and Hebrew who lived in Tübingen, Germany. Schickard built a machine that computed completely automatically the operations of addition and subtraction, and partially automatically, multiplication and division. Although Schickard had communicated with Johann Kepler about the machine, its existence was not widely known. The first well known computer was constructed by Blaise Pascal in France in 1642. His adding machine was not as advanced as Schickard's because it could not perform multiplication and division operations. But Pascal's contemporaries viewed the machine as a remarkable achievement (Goldstine, 1972).

The Leibniz Wheel

However, the digital machine, known as the Leibniz Wheel, invented by Gottfried Wilhelm Leibniz in 1673, could automatically compute all four basic operations. He also contributed to computer science by initiating the field of formal logic and suggesting the use of computers for testing hypotheses. Leibniz expected his machine would free men to work on problems whose laborious calculations would otherwise deter them (Goldstine, 1972).

George Babbage's Inventions

A similar motivation, supported perhaps by the first government subsidy to a scientist or engineer, led Charles Babbage, founder of England's Royal Astronomical Society and Royal Statistical Society² to invent his Difference Engine and his Analytical Engine in the early 1800's. Although his engines computed slowly, they could compute steadily for many hours. The Difference Engine was a special purpose computer, but the Analytical Engine, which had been inspired by Jacquard's card method for automating weaving, was to be a general purpose computer. But Babbage never completed either machine, partly because the technology of his day was not capable of producing the precision-machined gears and wheels his devices needed and partly because of vacillations in government financial support for his project. Babbage was the "first to establish the logical principle of digital computers" (Metropolis, Howlett, & Rota, 1980, p. 87); had he completed his engines, he would have constructed the first automatic computer, for "he almost alone, had produced the major ideas on which

all modern computers are based" (Goldstine, 1972). In addition, the world's first recorded program was written by Lady Lovelace, a daughter of Lord Byron, to illustrate how Babbage's Analytical Engine could be instructed to compute (Dubbey, 1978).

However, George Scheutz, a Swede, with help from Babbage, completed his own Difference Machine in 1834 and a larger and improved version in 1853. But the world was not to have its first working automatic computer until the 1940s, some 70 years after Babbage's death (Goldstine, 1972).

Invention of Hollerith Cards

The next major development was not a computer, but an invention that facilitated the input of information to a computer. Hollerith created the punched cards, known first by his name and later as IBM cards for the company that developed out of Hollerith's original firm established in 1911. Hollerith cards and the machines he invented to read and electro-mechanically count the holes punched in the cards and sort them was used in the U.S. Census in 1890. The use of the Hollerith system enabled the Census Bureau to ask and analyze more questions and get the answers faster and with less cost than was formerly possible (Goldstine, 1972).

A Modern Electromechanical Computer

It was not until 1937 that Howard Aiken, a graduate student and later a Professor at Harvard University, in collaboration with Thomas J. Watson, President of International Business Machines (IBM), started work on a digital computer. In 1944, using Hollerith counters and a

specially designed paper tape control for the program directing the operations of the machine, they produced a computer based on Babbage's principles. It was called the Automatic Sequence Controlled Calculator, Mark I. IBM President Thomas J. Watson presented it to Harvard University in 1944. However, its computing ability was limited (Goldstine, 1972).

Analog Computers

Analog devices competed with digital computers even in Babbage's day because they could compute more rapidly, albeit not as accurately as digital computers (Goldstine, 1972). The analog device built by Vannevar Bush at MIT to solve differential equations for computing ballistic trajectories and electrical engineering equations was constructed in 1930. By 1940, there were 8 full-size differential analyzers in the world (Goldstine, 1972).

Construction of ENIAC

However, analog computers had little appeal for scientists, such as astronomers, who need extremely accurate calculations. Their need continued to give impetus to development of digital computers that would provide the requisite computing accuracy. When the first electronic digital computer, the Electronic Integrator and Calculator (ENIAC), was completed at the Moore School of Engineering, University of Pennsylvania in 1946, and dedicated for use at the Aberdeen Ballistic Missile Center, analog and electromechanical computers became extinct. The ENIAC was 500 times faster than Harvard's Mark I computer and 1,000 times faster than George Stibitz's electromechanical one at Bell

Laboratories. The ENIAC contained 18,000 vacuum tubes, 70,000 resistors, 10,000 capacitors, 6,000 switches, was 100 feet long, 10 feet high, 3 feet deep, drew 140 kilowatts of power and weighed 30 tons. To enhance the reliability of the vacuum tubes in the computer, they were operated at 5.7 instead of 6.3 volts and left on continuously. The ENIAC was in operation from 1945 to 1955, when it was retired and moved from the Aberdeen Ballistic Missile Center to the Smithsonian Institute. Thus, ENIAC was responsible for the triumph of the electronic over the electromechanical computer, for the digital over the analog computer, and for initiating the computer revolution (Goldstine, 1972).

Contributors to ENIAC's Success

Many prior developments were responsible for ENIAC's success. Foremost, of course, was George Babbage's principles. Howard Aiken used these principles plus adaptation of IBM's accounting machines to construct his Mark I. Another contributor was Alan Turing who developed Babbage's ideas further in his paper on automaton in 1936; the principles in his paper were implemented in development of Britain's COLOSSUS machine used during World War II for cryptanalysis (Metropolis, et al., 1980). Boolean algebra with its famous formula, $x^2 = x \cdot x = x$, whose solutions were 1 and 0, was a scientific curiosity until Claude Shannon, founder of information theory, used Boolean algebra to design switching circuits. His work changed digital circuit design from an art to a science (Goldstine, 1972). John V. Atanasoff, professor at Iowa State College, in early 1940 was the

first to use vacuum tubes in a special purpose digital computer for solving simultaneous linear equations. His work inspired the men who worked on ENIAC: Herman Goldstine, in charge of operations; John A. Mauchly, consultant; and J. Presper Eckert, Jr., chief engineer. Many others also worked on the ENIAC, including John von Neumann, who as consultant explicated ENIAC's logic and subsequently wrote a paper to explain how to store a program in a computer. Von Neumann's paper served as a blueprint for the first machine to contain a stored program and a delay line, the Electronic Delay Storage Automatic Computer (EDSAC) (Goldstine, 1972).

After ENIAC's development the team that built it squabbled and disbanded over credit for patentable ideas, which lawyers finally decided were in the public domain; the decision probably greatly accelerated the computer revolution. Goldstine and von Neumann joined the Institute for Advanced Studies at Princeton where they helped construct the Electronic Discrete Variable Calculator (EDVAC). Mauchly and Eckert formed their own company, constructed the UNIVAC in 1951, and eventually sold their highly successful commercial company to a firm whose name was subsequently changed to Sperry-Rand (Goldstine, 1972).

A further development in main-frame computers was construction of a hierarchy of memory storage, such as iron cores, magnetic tapes, and punched cards; disc storage was added later. Creation of higher order languages, such as FORTRAN (Formula Translating System), allowed programs to be written in algebraic formula because a compiler program

had been devised to translate FORTRAN into machine language, the language which the machine understands.³

Although IBM had some competition, it was primarily responsible for commercialized computers, starting with its 700 series in 1953. Use of computers grew rapidly. In 1955, there were 88 domestic electronic digital computing systems; in 1957, 103; 1961, 222; and in 1964, 324 (Goldstine, 1972). The computer revolution had begun. It accelerated with the advent of minicomputers and microcomputers.

Minicomputers and Microcomputers

The definitional line between minicomputers and microcomputers is blurry (Forester, 1980), but minicomputers are relatively expensive. They cost between \$25,000 (DEC series PDP) and \$200,000 to \$300,000 (Data General NOVA). The most popular microcomputers, Apple and TRS80, are much less expensive. They cost less than \$5,000 for a complete package.

Development of mini- and microcomputers was the result of a drive to miniaturize computers. The drive began with the invention of the transistor by Bardain, Brittain, and Shockley in 1948. Texas Instruments' contribution was a silicon transistor in 1954. The first transistorized computer appeared in 1955, the year the ENIAC retired (Braun, 1981).

The next stage in miniaturization was the construction of large-scale integrated circuits (LSI). They consist of thousands of microminiaturized transistors on a sliver of silicon less than an inch on each side. This type of miniaturization was made possible by the

planar technique, devised by the Fairchild Semiconductor Company in 1958. The technique consists of a three-step process: oxidation, photo-etching, and diffusion. The packing density achievable by this process is now up to 100,000 components per chip (Braun, 1981).

The greatest breakthrough in miniaturization came when M. E. Hoff at INTEL developed a stored program on a semiconductor memory chip to run a computing circuit. He managed to put the central processing unit (CPU) on a single silicon chip by a photographic reduction of 500 times, followed by a photoengraving process. The chip, known as a microprocessor or a computer-on-a-chip, costed about \$10 and was more reliable than integrated circuits because it had fewer connections, the most common source of failures in computers. Hoff made the microprocessor into a general purpose computer (MCS-4) by attaching to it two memory chips, one to move data in and out of the CPU and the other to hold a program to drive the CPU. His invention contained 2,250 transistors on a 1/16 inch by 1/8 inch wide chip. Hoff's computer, first introduced in 1971, equalled the computing power of ENIAC. A second generation version, produced in 1973, had an 8080 central processor that increased the computational power by a power of 20; it could perform 100,000 calculations per second (Bylinsky, 1975).

In contrast to the industrial revolution, which uses large amounts of mechanical energy and fossil fuels, the electronics revolution requires little material or energy (Abelson and Hammer, 1971). Today computers have replaced wheels, gears, and other mechanical mechanisms to run motors, direct robots, and monitor and

control numerous operations, in addition to serving as calculators. They help in design problems, scientific and laboratory experiments, and simulation training. In industry and business, the different types of computers form a hierarchy of functions: microcomputers to control individual pieces of equipment, minicomputers to collect information from microcomputers for an entire factory, and large mainframe computers to collect information for corporate financial reports.

Educational researchers, such as the senior author's late mentor, Jack Holmes, employed IBM peripheral machines and computers almost from their inception, and taught him to use them when he started his graduate program at the University of California, Berkeley in 1951. Singer relates this story of his personal experience with IBM equipment:

I learned to punch cards, wire boards, run the sorter, and use the reproducer and lister; and in 1958, operated the IBM 701. For analyses of the factors underlying speed and power of reading, Holmes and I ran sequences of multiple regression equations, which we called substrata analysis, first on IBM's peripheral machines, next on the IBM 701 when it became available in 1958 and then on IBM 704 in 1960. We saw the time required for running the same problem drop from one year on the peripheral machines to five hours on IBM 701 (including turn-around time) to run three programs for computation of each multiple regression equation, to two minutes on IBM 704, and 30 seconds

on IBM 7090. The 701 had only about a 3,000 word memory; so most of the data had to be labeled by hand. Because the 704 had some 32,000 words for core storage, all the data would come out completely labeled. But we could no longer run the data data ourselves. Formalization and bureaucratization governed the operation of the IBM 704. Although we took courses in programming, we still had to hire a programmer to keep up with almost daily bulletins on changes in computer operations. Today my son who learned to program by immersing himself in it while in high school has a job as a programmer in the psychology department at UCR. We now own an Apple II computer, jam-packed with all the trimmings. Thus, I have personally witnessed and participated in the beginning of the computer revolution.

Use of Computers in Education

Education in general has lagged behind business and industry in use of computers. But since the advent of microcomputers, Education has begun to respond to the computer revolution (Singer, Dreher, and Kamil, 1982). To reveal the growth of computer usage in Education, we graphed the number and type of computer articles listed in the Education Index for the years 1950, 1960, 1970, and 1980. As shown in Figure 1, only one article occurred in 1960; that article pertained to computer literacy. By 1970, a dramatic change had occurred: 11 articles focused on computer literacy, 118 on computer-assisted instruction, 1 on testing, and 1 on computer-managed instruction. Articles on computer literacy and computer assisted instruction

increased in 1980, but the greatest gain was in testing and computer managed instruction.

Computers are probably used in most of the research reported in educational journals, but relatively little research has been reported on use of computers in Education. A time-sampling, Figure 2, shows that no research was reported in 1950; an article on literacy appeared in 1960; eight articles, all on computer assisted instruction were published in 1970; 18 articles occurred in 1980 on computer literacy, 10 on computer assisted instruction, 5 on testing, and 2 on computer managed instruction. Thus, this time sampling shows that research on use of computers is accelerating.

Education has to prepare students for a world that in 1985 will have an estimated 20 million computers and require computer literacy in 75 percent of its jobs (Newsweek, 1981). In recognition of this task, Education has begun to rapidly purchase and use computers. Concomitantly, the research community has begun to focus on use of computers in education. To determine what we now know about use of computers in education, we have decided to review the last three years of this research. Our review is organized into five categories: computer assisted instruction, testing, computer managed instruction, cost effectiveness, and literacy. However, we have also included in our review some research that has occurred prior to the last three years in order to make our review more coherent and complete about our knowledge on the use of computers in Education.

Computer Assisted Instruction

Computer assisted instruction (CAI) is based on the principles of programmed instruction. The three types of CAI instruction are tutorial, a self-contained program with machine-based decisions for linear or branching programming; drill and practice programs, designed to supplement teacher-based instruction; and programs in which students interact or converse with the computer and control the information sequence (Mason & Blanchard, 1979; Blanchard, 1980).

The first computer-based reading program was conducted by Atkinson in the Brentwood Elementary School in East Palo Alto in 1963 (Atkinson & Hansen, 1966). A computer-assisted arithmetic program was conducted at Stanford in 1966-68 (Suppes & Morningstar, 1972). Students in both programs participated by sitting at terminals in their classrooms hooked up to a main-frame computer at Stanford. Among the research findings on this type of computer-assisted instruction is that students can learn acquisition processes from computers as well as from teachers (Lumsdaine, 1963; Kulik, Kulik & Cohen, 1980), sometimes even better because the computer provides feedback without embarrassment or negative affective responses (Magidson, 1977). Furthermore, the range of individual differences in achievement increases because students can progress through the computer program at their own rates, which may account for the one-third faster instructional time (Kulik, et al., 1980).

Although CAI has been successful, critics in the early stages of computer assisted instruction objected to its impersonalized teaching, standardization of education, simplification of curriculum in order to

adapt to CAI limitations, and computer control over men. Suppes and Morningstar (1972) replied succinctly and effectively to these objections. They retorted that CAI provides more personalized instruction because students experience more individualization and less lockstepping under CAI than under teacher instruction. They argued that standardization is not a function of the computer but of how the computer is used; in fact, CAI programs can collect data as students progress through a program and analysis of the results can lead to modification in a CAI program faster than a textbook can be revised. Moreover, machines can free teachers from drudgery.

Use of computers for drill and practice may be criticized but drill and practice are important for acquiring automaticity in sub-skills underlying acquisition of basic skills, such as word recognition in reading, number facts in arithmetic, and spelling in written communication. Automaticity in these functions enables individuals to allocate attention to reading comprehension (La Berge & Samuels, 1976), arithmetic problem solving, and communications of ideas. However, the issue is not whether drill and practice are necessary, but whether CAI can provide drill and practice in interesting and meaningful ways. With the advent of interactive programming and graphics the limitation is not in CAI per se but in the imagination of programmers.

It may not be long before schools begin to use CAI instruction in a great variety of ways. The army has already combined computers with videodiscs and television for simulated training and imitative

learning, repair information, and various job functions, such as recipes for cooks and bakers (Morris, 1981). The Michigan Center for Research on Learning and Teaching is using computers for composition classes, laboratory instruction, simulation of laboratory experiments, instructional games in business, sociology, and education, and development of computer literacy for graphics in engineering, linear programming in business, information systems in law, patient records in medicine and management of instruction in education (Zinn, 1980).

Research on computer assisted instruction is also going on in various laboratories. For example, Anderson, Klassen, Hansen and Johnson (1980-81) found that an experimental group of 350 students in grades 9 to 11 developed more favorable attitudes towards computers after learning a CAI science lesson and retained the information over a six month period at a significantly higher level than a control group. Collins (1977) has programmed a computer to conduct a Socratic dialogue with a learner. The dialogue has students make inferences that lead them to new knowledge. The program can also be used as a simulation device for training teachers in the Socratic method. In another laboratory, Schank (1982) has demonstrated how a computer can read and comprehend.

Carver and Hoffman (1981) have employed a technique of programmed prose which automatically converts regular reading material into training materials. These materials were then used by inserting two choices for every fifth word in a passage. The student in interacting with the computer selects a choice as he reads and gets immediate

feedback from the computer on whether the choice is correct. Since the students can read and reread the material on the Plato IV computer, Carver and Hoffman may also be improving the reading performance of poor readers at the high school level by the method of repeated readings; in this method, students read the same material several times until they achieve mastery. Each time they may have been accomplishing a different purpose, first to recognize all the printed words, then to get their meanings, and finally to make inferences, interpretations, and evaluations (Samuels, 1979). Ntiri (1981-82) used a combination of materials and computer programs for diagnosing and teaching mastery of programmed modules in reading and math to disadvantaged youths. Chapman and Fleming (1982) reported that the American Chemical Society has developed and field-tested via the Plato computer system in industrial sites an interactive program with simulated experiments for teaching polymer chemistry; the computer lessons include diagnostic pre- and post-tests, review questions, and opportunities to stop the program and write notes on the computer for the teacher to read and respond later. Using interactive graphics and the touch sensitive input of the PLATO system, Hofstetter (1980) devised an ear-training program on a digital synthesizer and a drill and practice technique in chord perception for teaching college freshman music majors in the guido chord program and analyzed their responses; he found they learned the chords, were able to transfer knowledge gained from chords in open position to closed position, and through analysis of student responses he identified five

principles of chord-quality confusions. Alessi, Siegel, Silver and Barnes (1982-83) developed for the PLATO system a reading instruction program based on SRA Reading Laboratory 4A passages for teaching information finding and paraphrasing to adult basic education students in a correctional institution whose scores on the Test of Adult Basic Education was between grades 4-6; after an average of sixty-seven days to complete 40 sessions (20-40 minutes per session, one or two per day), the results showed the reading students gained significantly on both objectives and maintained their gains over a month interval but a math treatment group did not make any significant gain. Interesting features of the program are fade outs from cued to uncued formats, and correction procedures which point out why responses are incorrect. Students start by underlining parts of the text that answers literal wh-questions; if a student error persists, a graphic correction appears that consists of an arrow that points from the question to the answer in the text.

However, computer programs can vary in quality and effect. For example, Diem and Fairweather (1980) found their PLATO reading program developed by Control Data Corporation, used on inmates in a correctional institution, resulted in achievement gains after eight weeks of instruction but not significantly more than a control group taught by lecture, rote recitation, and team teaching but no individualization. The curriculum started with instruction in prefixes and suffixes, then progressed to words, sentences, and paragraphs. The inmates reported they did not find the materials were "adult-like."

Although computer simulation seems to be more attractive than presentation of programmed instruction via computer, it may not be more effective. Orgren (1979) compared a computer program that simulated library situations based on actual librarian encounters in which the librarians ask patrons questions to clarify their requests about characteristics of major reference works and received information as needed to answer their questions versus presentation of the same information in a predetermined sequence followed by questions for the librarians to answer. The computer simulation model was programmed to respond to key words in the librarian's questions; if the key words did not appear, the program would ask the librarian to restate the question. Both techniques were equally effective for recall of information and for more complex levels of knowledge, such as synthesis and evaluation of information.

A large number of computer programs is available for each level of instruction and for many subject areas. They have been used as low as the second grade (Carlstrom, 1980). Many commercial textbook publishers are preparing software for computers (Polin, 1981). In 1981-82, 23 books on computers were available for students in grades 2-12 (Di Angelo, 1985). Lists of software can be found in the publications of Mason and Blanchard (1979) and Singer, Dreher, and Kamil (1981).

Attitudes Towards Computers and Computer-Assisted Instruction

Just as students react affectively towards teachers, so they do towards computers and computer-assisted instruction. In general, they

maintain or develop a positive attitude. Cavin, Cavin, and Lagowski (1981) found that females developed a more positive attitude towards CAI in a chemistry course while males maintained their already positive attitudes. They suggested the positive attitudes occurred because the materials were instructionally adequate, the students were not frustrated by overcrowded systems or with long tie delays or annoyed by poorly operating systems, but CAI did not affect their attitudes towards chemistry. Poore, Quales, and Brown (1981) also found students reacted negatively when they were frustrated by poorly or slowly functioning equipment or long waiting periods for a terminal. Negative attitudes resulting from computers can be long lasting and become generalized (Anderson, et al., 1981). Ntiri (1981) reported that a combination of CAI plus workload and video cassette drill and practice, consultation with instructors, and individual counseling helped disadvantaged youth in a basic skills program (CETA) whose achievement levels were between grades 4.5 to 6.5 improve in reading comprehension and mathematics. The CAI materials were in modular form; students progressed as they mastered objectives. The program took 520 instructional hours over a 26 week period in four hour daily sessions; it included diagnosis and prescription in reading, mathematics, and language. Students were taught in groups from two to 16. When interviewed, they thought the training would help them in finding jobs in work skills and in daily living.

Whether students develop a favorable attitude towards CAI may depend on personality factors. Hoffman and Waters (1982), using the

Myers-Briggs type indicator personality test based on Jungian typology, found that military students learning Morse Code by CAI who stayed in the course were "sensing types" who have the ability to quietly concentrate, pay attention to details, have an affinity for memorizing facts, and can persevere with a task to completion. Those who tended to drop the course were "extraverted perceptive types" who like variety and action; they prefer theory to application; they tend to pay attention to the broad picture and not the details; they like harmonious group projects, team competition, and opportunities to create new ways of doing things."

Although students may achieve equally well in a CAI as in a lecture class, the CAI students may feel isolated from teachers and peers and frustrated by problems they cannot solve or are uncertain they solved correctly. When Tsai and Pohl (1980-81) discovered their college statistics students exhibited these feelings, they supplemented a programmed instruction group and a CAI group with lessons in which the teacher previewed the materials, answered students' procedural and content questions, and provided individual assistance to students who could not solve problems on their own. Differences in achievement levels led Tsai and Pohl to conclude that "simply reading" a programmed textbook or participating in lecture/discussions classes and completing homework problems were the least effective teaching environments (p. 123). For higher achievement on a multiple choice test, CAI alone or supplemented CAI or supplemented programmed texts were the more effective learning environments.

Attitudes towards computer use may become even more positive after a delay interval. Anderson, Klassen, Hansen, and Johnson (1981) taught 9th and 11th grade high school students a brief 15-20 minute program on the effect of water pollution on survival of fish. The experimenters varied the degree of system malfunction and use of enriched display (animation, graphics, and color). These treatment factors had no significant effects on achievement, but the system malfunction led students even six months later to anticipate computer failure. Also, after six months students were even more knowledgeable about computers perhaps because they began to seek out and accumulate computer knowledge.

Testing

Essential to any instruction is determination of student achievement and progress towards instructional goals, often operationally defined by tests (Rothkopf, 1980; Singer, 1980). For assessing, evaluating, and analyzing multiple choice tests, the computer is vastly superior to the teacher because the computer can more reliably present stimuli consistent with test standardization requirements and feed the results back to teachers and students as soon as the test is over. Students can also use computers, programmed with teacher-posed questions on the textbook, lectures, and collateral reading, to test themselves. For example, students enrolled in large lecture courses in sociology tested their own progress via a computer; the results indicated the self testing was more beneficial for those students whose ability and knowledge in the course was low upon entry

(Lavin, 1980). Computer programs can also diagnose and provide feedback for timely instructional intervention. Brown and Burton (1979) have devised such a program for arithmetic. It could become a model for future classroom testing programs in arithmetic. Testing and making instructional decisions is only part of the management of instruction that computers can facilitate and enhance.

Computer Management of Instruction

Computer managed instruction may be defined as use of computers for retrieval of diagnostic and evaluative information to plan lessons, to do research on student-learning, and to ascertain the effectiveness of teaching strategies and instructional materials (Thompson, 1980). Teachers who use computers for computer-assisted instruction and for management of instruction can have more time available for planning instruction and for guiding and counseling individual students (Glaser and Cooley, 1973). In short, a computer can do the repetitive teaching functions of direct instruction and testing, freeing the teacher for more individualization and the more creative aspects of teaching.

Cost Effectiveness

Computers are cost effective under certain conditions. Jenkins and Denkert (1981) reported use of a PLATO IV student terminal installed in a university library by the staff of Computer Education Research Laboratory from the University of Illinois. The terminal had a keyset, random-access image selector, and touch input panel, and gave users access to the Mercer system, a curriculum index which covers a

wide variety of subject areas. Use of the science programs increased over a three month period. Chemistry students reported the computer helped them understand steps in the titration process and enabled them to perform better in their laboratory work. The chemistry department was the heaviest user, followed by the biology department. Students reported a favorable attitude and the more they used it, the less intimidated they felt. Daily use increased from 3.9 to 8.2 hours/day and operational cost was reduced from \$11.40 to \$4.20.

Although Poore, Qualls, and Brown (1981) found that high school students who had failed the state's competency test were able to improve 1.5 grade-equivalents after 20 hours of lessons on the Plato Basic Skills Math lessons supplemented with basic skills and problem solving workbook, the cost of raising the student from a 5.8 to an 8.0 grade equivalent was \$147 for 20-30 minutes per day on the computer terminals.

Research is just beginning on cost effectiveness of computers. Spuck (1981) points out that computers are likely to be more cost-effective when they have programs that are geared to large undergraduate courses than to more specialized upper division and graduate courses. However, he recognizes that computers even if they were less cost effective, may be necessary for advanced specialized courses; for example, for simulations on nuclear reactors and genetic experiments. In general, Spuck notes that the CAI costs are decreasing while faculty instruction costs continue to increase.

Costs for CAI include software development, personnel training, hardware, maintenance, instruction time, telecommunications, electricity, facilities, environmental control. Another way of viewing costs is in production (specifying instructional objectives, writing a script, videotaping, and designing a CAI unit), distribution (communication, equipment, television transmitters, cable network, and time-sharing computers), and reception (antennas, receivers, video disc players, and computer terminals). Production costs are fixed, but distribution and reception costs increase with number of student users, duration, and frequency. Also, the lifespan of the courseware has to be computed; more advanced courses change more rapidly than do introductory courses. Costs for Plato, based on 4000 terminals, 200 hours/week, and a five year life expectancy was about \$.51 per student hour.

Slowing down the rate of change in use of computers is not only costs, but also faculty resistance. To encourage faculty to develop software, Spuck suggests the university will have to provide a reward system for quality courseware development, establish royalty and copyright agreements, recognize that a balance of live and technological delivery systems is required, and the rights, values, and dignity of faculty and students must be considered. Some faculty fears of eventual replacement by technology may be well-founded: they may have to retool for alternate occupations. Faculty is also disenchanted with the fact that studies reveal that differences in learning are no greater with media than with conventional methods;

therefore, some advantage will have to be found for technological instruction, such as simulation of otherwise dangerous instruction, or provision for access to instruction in isolated places, or instructional delivery in home settings (Spuck, 1981).

However, faculty and administrators have little choice. Students are forging ahead with arcade games, home computers, and use of computers in school. To find out what is currently going on in schools, it is necessary to ask the students and the teachers involved in computers, not the administrators who are lagging behind the revolution wrought by computers (Mitchell, Mitchell, & Mendez, 1981). But administrators are beginning to find suggestions to help them adapt schools and instruction so that they can use computers to maximize instruction, minimize costs, and select programs and materials that are up-to-date with current curricular considerations. For example, Langer (1982) has made some suggestions for computer programs that will provide process-oriented instruction, reading instruction consistent with the interaction theory of reading, and procedures for initiating use of computers in a school.

Computer Literacy

Within one generation of electronic computers and only a decade after the advent of microcomputers, Education is beginning to emphasize computer literacy. It has begun to prepare students for a world occupied by computers. Indeed computer literacy will undoubtedly join the three R's as a basic skill likely to be developed in a curriculum that spans the grades and continues on to college and

graduate school. Students will find they vary from minimal to maximal competency in computer literacy, but how these extremes are defined will probably be as controversial as the concept of reading competency is today.

As computers become more readily available, we shall have to ask such educational questions as what information must people acquire and carry about in their heads now that computers are readily available for calculating, spelling and even reading print aloud, as the almost unbelievable Kurzweil machine can do (Cushman, 1980). Do we still need to drill students on number facts in arithmetic, or should we devote the time instead to the conceptual basis of mathematics that was emphasized, perhaps twenty years too soon, in the so-called new math? How do computers affect students' thinking and problem-solving abilities? Does computer assisted instruction with its perpetual patience favorably affect learning and motivation to learn? Can teachers, relieved of the time burden for direct instruction, be more creative and enhance the education of students? How can teacher pre-service and inservice programs be modified to maximize the favorable effects of computers? Some of these questions are also being asked at the Michigan Center for the Study of Learning and Teaching (Zinn, 1980). The answers may eventually lead us to realize that the computer can and is likely to cause a dramatic change in teaching and learning at all levels of Education.

Footnotes

¹Goldstine's engaging intellectual history of computers is a rich source of information on the development of main-frame computers, much of it a first-hand account because Goldstine was in charge of the construction of the first general purpose electronic computer, the ENIAC. A companion volume, consisting of oral histories of the main contributors to the development of computers in the twentieth century, has been edited by Metropolis, Howlett, and Roto (1980).

²Although Babbage was appointed a professor of mathematics at Cambridge, he never resided nor gave a lecture there (Dubbey, 1978).

³Simpler languages, such as BASIC (Beginner's All-Purpose Symbolic Instruction Code), LOGO, and SMALLTALK, devised in the 1970s, further extended computer usage by making programming and interaction with computers available to schools and homes.

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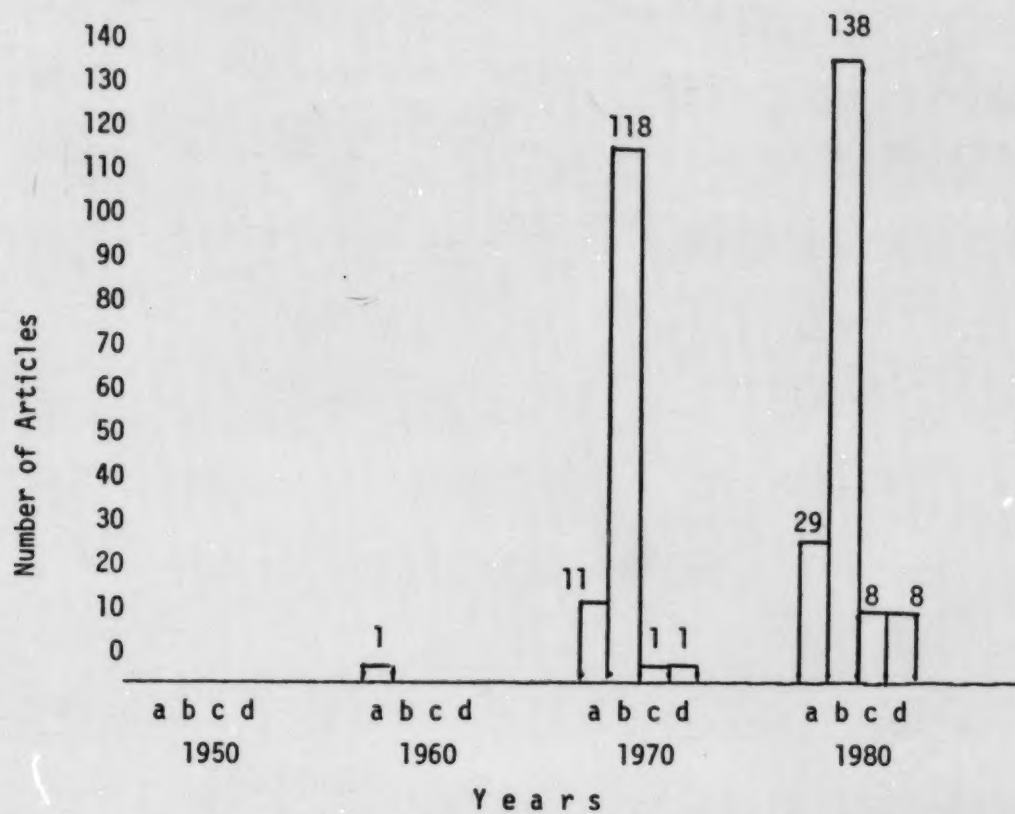
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Symbols: a = Computer Literacy
 b = Computer Assisted Instruction
 c = Testing
 d = Computer Managed Instruction

Fig. 1. Number of journal articles on computers in the Education Index.

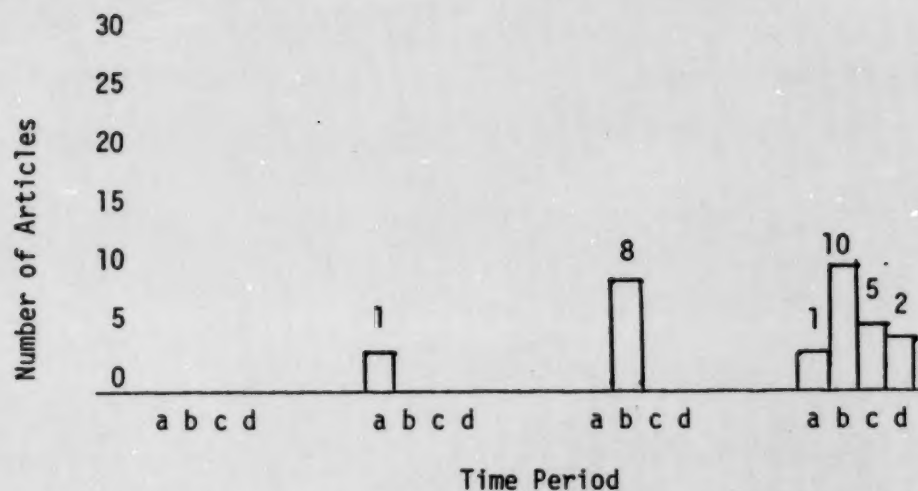


Fig. 2. Research articles on (a) computer literacy, (b) computer assisted instruction, (c) testing, and (d) computer managed instruction listed in Education Index (1950 and 1960) and Current Index to Journals in Education (1970 and 1980).